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STRUCTURAL BEHAVIOUR OF SINGLY REINFORCED OPS BEAMS

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ABSTRACT: Concrete using oil palm shell (OPS) as coarse aggregate has been found useful as lightweight concrete and strengths of up to 28 MPa have been attained. To further investigate its suitability for structural purposes, additional tests are required. Therefore, this paper presents an experimental investigation on the modulus of elasticity and flexural behaviour of three reinforced OPS concrete beams with different effective depths and reinforcement ratios. From the investigation, OPS concrete show promising results for use as structural members, especially for the construction of low cost houses in areas where oil palm is found in abundance.

Keywords: Lightweight concrete, Renewable resources, Flexural behaviour, Modulus of elasticity, Deflection

1. Introduction

Nearly 80% of the resources used today are non-renewable. Due to the scarcity of conventional raw materials, engineers are focusing more on developing construction materials with renewable resources. The appearances of new types of concrete, especially for lightweight concrete production are becoming more common nowadays. In Malaysia, the high availability of oil palm shell (OPS) waste at no cost and the potential pollution caused by these wastes have led to studies into the possible use as aggregates in concrete. Malaysia is currently the largest producer and exporter of palm oil, generating over 4 million tonnes of waste OPS annually.

Concrete using OPS as coarse aggregate has been found useful as lightweight concrete (Mannan and Ganapathy, 2004) and even compressive strengths of up to 28 MPa have been achieved (Teo et al., 2005a). OPS aggregates have bulk densities in the range of about 500 to 600 kg/m^3. When incorporated into concrete as coarse aggregates, the resulting hardened concrete is lightweight with air-dry densities of about 1900 kg/m^3.

The use of lightweight concrete in construction has many benefits. A significant amount of dead load reduction can be observed when lightweight concrete is used. Structures constructed using lightweight concretes can produce a load reduction of approximately 15 to 30 percent as compared to structures built with normal weight concretes.

Recent investigations have also shown that OPS concrete has good potential as structural members (Teo et al., 2005b). Therefore, the purpose of this paper is to investigate further the structural properties of OPS concrete by determining the modulus of elasticity and conducting full-scale prototype singly reinforced concrete beam tests.

2. Materials Used

All materials used in this investigation were locally obtained. These included ASTM Type 1 cement, river sand as fine aggregate and OPS as coarse aggregate. The properties and grading curve of the river sand and OPS aggregates are shown in Table 1 and Fig.1 respectively. A Type-F naphthalene sulphonate formaldehyde condensate based superplasticiser in aqueous form was also incorporated and these properties are presented in Table 2.

Table 1. Properties of river sand and OPS aggregate

Properties	River sand	Oil palm shell (OPS)
Maximum grain size, mm	1.18	12.5
Shell thickness, mm	-	0.5 – 3.0
Specific gravity	2.45	1.17
Bulk unit weight, kg/m^3	1500-1550	500-600
Fineness modulus	1.40	6.08
Los Angeles abrasion value, %	-	4.90
Aggregate impact value, %	-	7.51
Aggregate crushing value, %	-	8.00
24-hour water absorption, %	3.89	33.0

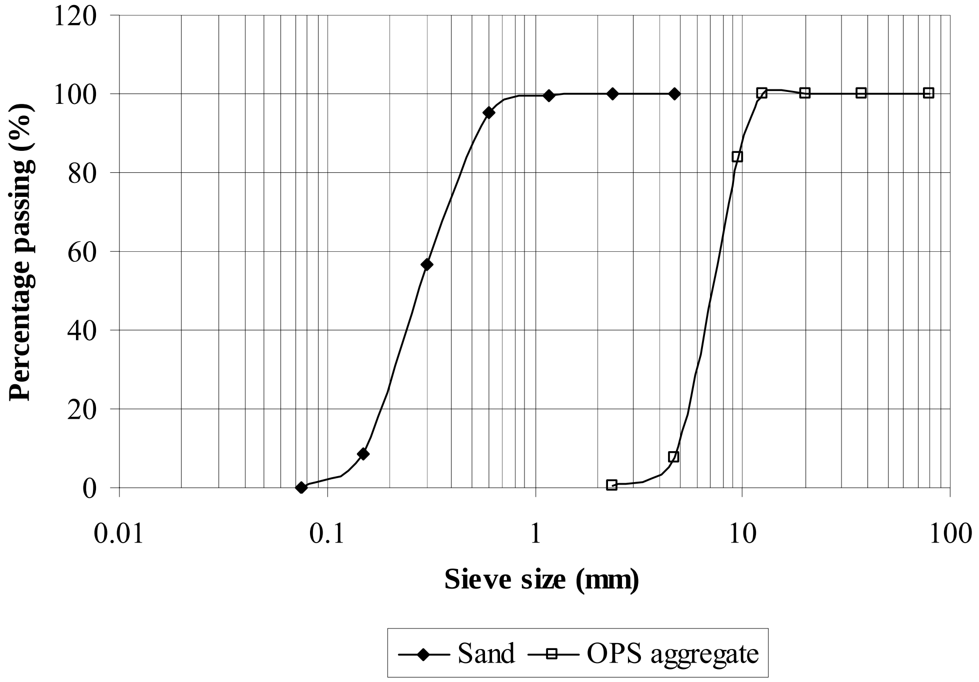

Fig 1. Grading of river sand and OPS aggregate

Table 2. Properties of superplasticiser

Appearance	Dark brown liquid
PH (concentrate)	6.0 – 8.0
Boiling point/boiling range	100ºC approx.
Relative density	1.200 – 1.220

3. Mix Proportions

The acceptable mix comprised of 510 kg/m^3 cement, 848 kg/m^3 sand and 308 kg/m^3 OPS with a free water/cement ratio of 0.38. This mix proportion was used throughout the entire investigation. The cement content used in this study is within the range for lightweight concrete (Mindess et al., 2003).

4. Experimental programme

4.1 Specimen Preparation

Mixing of concrete was carried out using a rotating drum type mixer with 200 litres capacity. To ensure uniformity in the mix the coarse aggregates (OPS) were fed into the mixer first followed by the fine aggregates (sand) and cement. In the rotating state, the components were mixed while water and superplasticiser were added. The mix was then cast into moulds. The modulus of elasticity specimens were prepared using 150 x 300 mm cylinders and tested in accordance to BS1881: Part 121. For the prototype beams, they were cast in wooden formwork.

Immediately after casting, all specimens were covered with plastic sheet and left under shade for 24 ± 4 hours. After that, the moulds for the modulus of elasticity specimens were removed and the formwork for the beams were stripped. All specimens were cured for another six days with wet burlap, afterwhich they were left in ambient laboratory conditions until testing. Specimens were tested at an age of about 56 days.

4.2 Beam Details

All test beams had rectangular cross-sections with a total length of 3200 mm and a span of 3000 mm. The variables were the effective depth and reinforcement ratio. The beam sizes and length were also chosen to ensure that the beams would fail in flexure. The details of the beams are presented in Table 3.

Table 3. Beam details

Beam no.	Effective depth, d (mm)	Tension reinforcement no. and size	Beam size, b x D (mm)	Area of steel reinforcement, A_s (mm^2)	$\rho = A_s/bd$, %	Stirrups size and spacing (mm)
SR1	225	2Y10 + 1 Y12	150 x 255	270	0.80	R6-150
SR2	250	3Y12	150 x 281	339	0.90	R6-100
SR3	275	2Y12 + 1Y16	150 x 307	427	1.04	R6-80

4.3 Beam Testing Setup

The beams were positioned on steel supports in the steel loading frame and tested under a four-point bending system. A schematic drawing of the set-up is shown in Fig. 2. 100 mm plunger travel LVDTs (linear voltage displacement transducers) were positioned at several locations including one at midspan and two directly below the loading points to determine the vertical deformations.

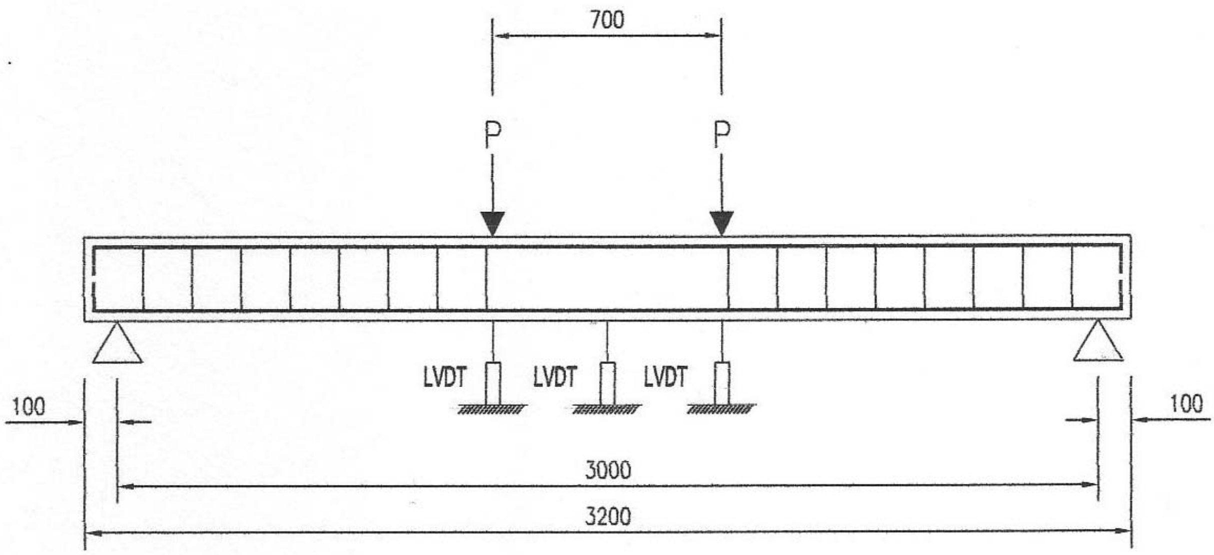

Fig. 2 Beam testing set-up

4.4 Beam Test

The test was carried out using a Shimadzu 1000 kN hydraulic actuator. Before testing, initial readings were observed and recorded. At each load increment the vertical deflections in the pure bending region were captured via a data acquisition system. The development of cracks was observed and the crack widths were measured using a hand-held microscope with an optical magnification of ×40 and a sensitivity of 0.02 mm.

5. Results and discussions

5.1 Fresh concrete properties

The slump of the OPS concrete was in the range of 50 to 70 mm. The slump obtained showed that the OPS concrete has a medium degree of workability and is within the range of a workable concrete. The air content was fairly high with a value of 5.5 percent. This could be attributed to the highly irregular shapes of the OPS aggregates which prevented full compaction to be achieved.

5.2 Modulus of Elasticity

The modulus of elasticity is an important characteristic for structural concrete because it is a measure of its stiffness. For conventional Grade 25 concretes, the modulus of elasticity is typically about 24 GPa. The modulus of elasticity obtained for OPS concrete was 5.07 GPa, which was only approximately 20% of that of conventional granite concretes. A typical stress-strain curve for OPS concrete is shown in Fig. 3. The strain corresponding to maximum stress is approximately 0.006. One particular concern for OPS concrete is the low value of elastic modulus and this was further investigated from the prototype beam testing.

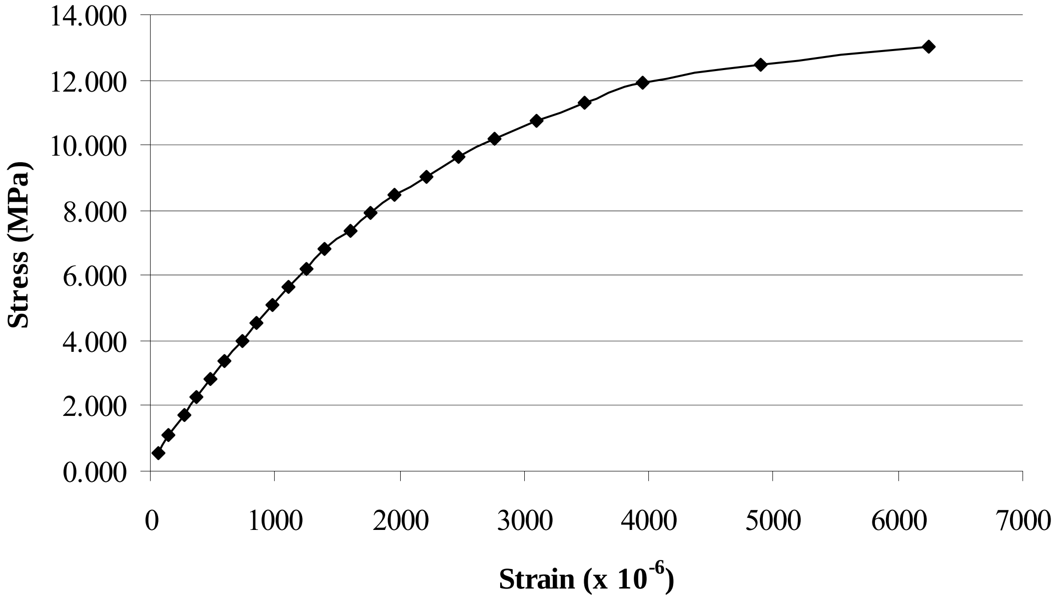

Fig 3. Stress strain curve

5.3 Prototype Beam Test

All beams showed typical structural behaviour in flexure and considerable amount of deflection occurred prior to failure. Since the beams were designed as under-reinforced beams, the tensile steel yielded before crushing of the concrete cover in the pure bending zone. Final failure occurred due to crushing of the compression concrete.

The theoretical design moment and the experimental ultimate moment are presented in Table 4. The theoretical design moment of the beam was predicted using the rectangular stress block analysis in accordance with BS 8110. It was observed that for all beams, the experimental ultimate moments were much higher than the theoretical design moment.

Table 4. Theoretical design moments and experimental ultimate moments

Beam No.	Theoretical design moment, kNm	Experimental ultimate moment, kNm	% higher
SR1	24.10	27.77	15.2
SR2	32.32	37.09	14.8
SR3	43.72	52.61	20.3

The experimental deflection at service loads (dead load + live load) was 11.10 mm, 10.45 mm and 10.05 mm for beams SR1, SR2 and SR3 respectively. Although OPS concrete has low modulus of elasticity, the deflection under the design service loads is acceptable as the span-deflection ratios ranged between 270 to 299 and are well within the allowable limit provided by BS 8110, which is span/250.

The crack development of the OPS concrete beams is shown in Fig. 4. The crack widths at service loads for beams SR1, SR2 and SR3 were 0.23 mm, 0.18 mm and 0.17 mm respectively. These crack widths were well within the within the acceptable limiting crack widths necessary for durability requirements as per BS 8110.

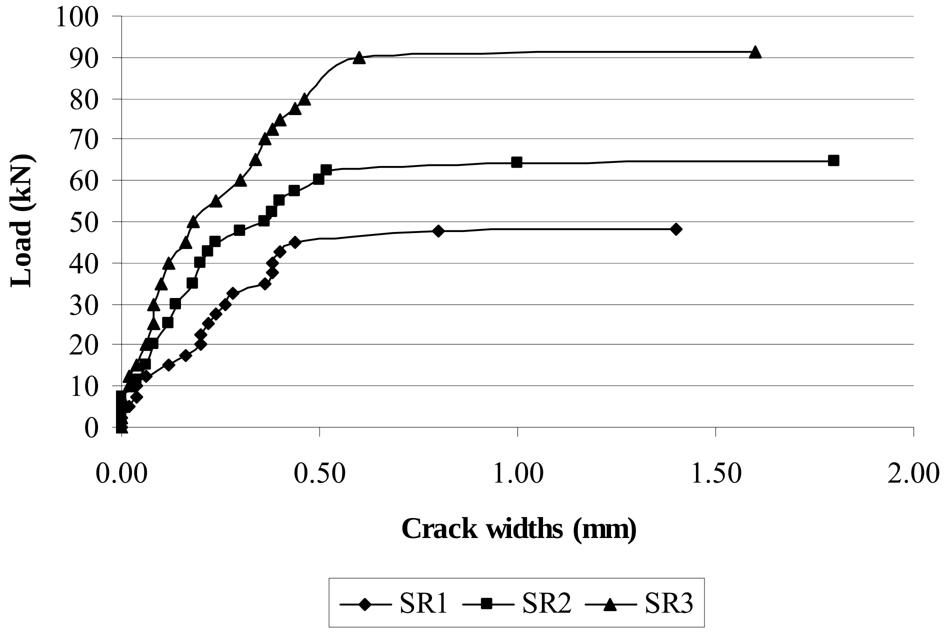

Fig 4. Crack development

6. Conclusions

The use of OPS as aggregates in concrete minimises the demand on finite resources of stones and gravels. In general, OPS concrete shows promising results as structural members, especially for the construction of low cost houses in areas where oil palm is found in abundance such as in oil palm plantations. From this experimental campaign, the following conclusions can be drawn.

i) OPS concrete has a low modulus of elasticity, which is about 20% of that of conventional granite concretes.

ii) All beams showed typical structural behaviour in flexure and considerable amount of deflection occurred prior to failure.

iii) The experimental ultimate moments of OPS concrete beams were approximately 14.8% to 20.3% higher compared to the theoretical design moments as stipulated by BS8110.

iv) At service loads, the deflections and crack widths were well within the allowable limit provided by BS 8110.

7. Acknowledgement

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